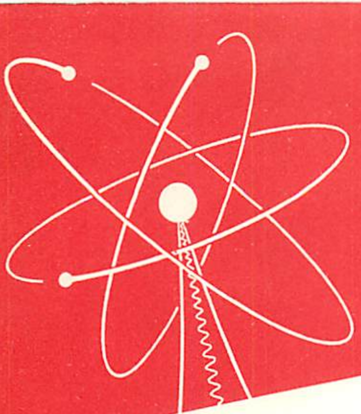
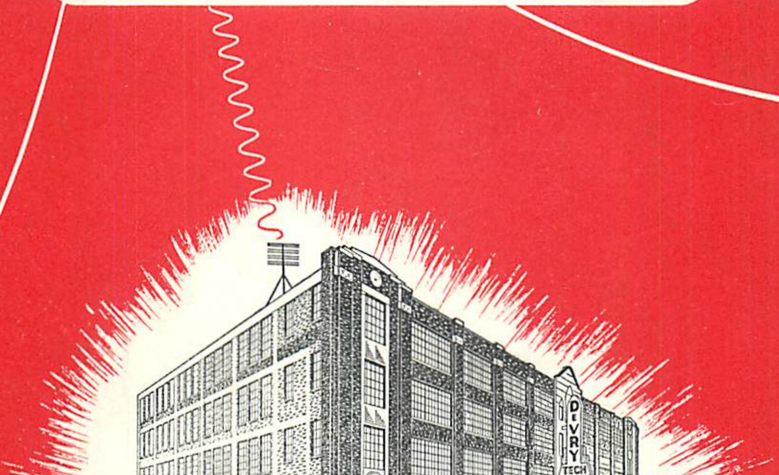


AFC CIRCUITS

Lesson T2C-14A



-14

DeVRY Technical Institute
4141 W. Belmont Ave., Chicago 41, Illinois
Formerly DeFOREST'S TRAINING, INC.

T2C-14A

AFC CIRCUITS

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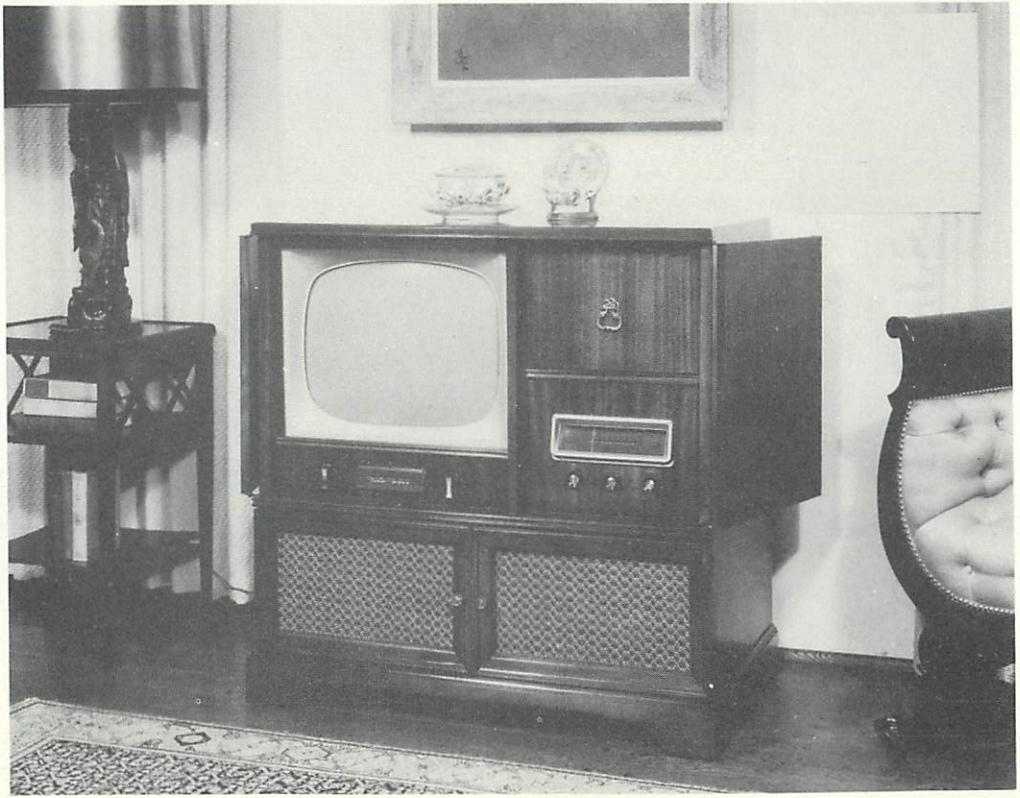

Due to the effective AFC circuits used in modern television receivers only two pairs of knobs are needed on the front panel. The hold controls are so rarely used that they are placed in back or recessed behind the name plate.

Courtesy Pacific Mercury TV Mfg. Corp.

AFC CIRCUITS

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Vigilance in watching opportunity; tact and daring in seizing upon opportunity; force and persistence in crowding opportunity to its utmost possible achievement—these are the martial virtues which must command success.

—Austin Phelps

AFC CIRCUITS

AUTOMATIC FREQUENCY CONTROL

In the television receiver, the vertical and horizontal sweep oscillators have somewhat different requirements in regard to stability of oscillation frequency. Both must be capable of being held in exact synchronism by the received sync pulses, and yet be unaffected by noise pulses. Also, both must be able to change phase within a reasonable length of time when the receiver is switched to another channel, or when there is a station break in a network program, etc. However, because of their difference in operating frequency, the horizontal oscillator goes through 262.5 cycles in the time it takes the vertical oscillator to complete one cycle. Therefore, without producing a noticeable effect on the picture, the horizontal oscillator can change phase gradually during a period 'more than 200 times as long as it takes the vertical oscillator to shift to the phase of the new sync signals.

Considering this situation from another viewpoint, the vertical oscillator must be capable of changing phase more than 200 times as fast as the horizontal oscillator. For this reason, the vertical oscillators employed have minimum "inertia". At almost any point in a cycle, the incoming sync pulse can interrupt the cycle and cause a new cycle to begin in phase with the pulse. An oscillator cannot be stable and at the same time extremely responsive to sync pulses. Thus, frequency stabilizing methods are not used with the vertical oscillator. Fortunately, most noise pulses are blocked by the sync circuits and the integrating filter circuit, since such pulses could throw the vertical oscillator out of synchronism easily.

Because of their 15,750 cps frequency, compared with the 60 cycle vertical pulses, the horizontal synchronizing pulses have a much closer resemblance to the pulses produced by most noise energy. Therefore, the RC circuit designed to pass the horizontal pulse output of the sync circuit presents less opposition to the high frequency noise pulses than does the integrating circuit preceding the vertical oscillator. As a result, noise pulses would cause considerable more loss of horizontal synchronism than vertical, if special means were not employed to increase the frequency stability of the horizontal sweep oscillator.

As explained in the lesson on sweep oscillators, one method consists of using the flywheel effect of an LC tank circuit. In the horizontal sweep oscillator, the pulse generator is an LC sine wave oscillator, or a blocking oscillator or multivibrator which includes an LC stabilizing circuit. In addition, this stable oscillator is operated in such a manner that neither noise nor sync pulses are applied to it. Its frequency of operation depends upon circuit values of L, R, C, and bias.

A long series of incoming sync pulses determines the magnitude and polarity of a direct voltage developed by a control circuit. In the case of the sine wave type horizontal oscillator, the developed direct voltage determines the tuning of the LC circuit. With the other oscillator types, the total grid-cathode bias is determined by the direct voltage output of the control circuit. Thus, in every case, the sweep oscillator frequency depends upon the repetition rate of a long series of sync pulses, and is not influenced by a few random noise pulses.

This horizontal control circuit arrangement or system is known by various names such as automatic frequency control (afc), automatic sync control, and horizontal afc. A number of afc systems have evolved. In each system, the received sync pulses are "compared" in some way with the output of the sweep circuit. As illustrated by the block diagram of Figure 1, the comparing is done by the horizontal control circuit which receives sync pulses from the sync amplifier and a sine wave or sawtooth voltage from the sweep oscillator or amplifier. From the control circuit, the sweep oscillator receives a direct voltage, the polarity and magnitude of which depends upon the phase relations between the compared signals.

Depending upon the type of voltage applied by the sweep circuit to the control circuit, or the manner in which the comparing is accomplished, afc systems fall into three general categories: (1) sine wave; (2) sawtooth; (3) pulse-width. Each of these systems and the circuits employed are described in this lesson.

SINE WAVE AFC SYSTEM

Figure 2 is a block diagram of the essential elements of the sine

This signal generator provides a horizontal sync voltage for synchronizing the sweep generators of the oscilloscope used with it during receiver alignment.

Courtesy Triplett Electrical Instrument Co.

wave type automatic frequency control system. After removing the sync pulses from the complete video signal, the sync circuits pass them on to one input of the discriminator. As shown, the second input of the discriminator receives a voltage from the horizontal sweep oscillator.

The discriminator employs two diodes connected so that when the applied sync pulses and the oscillator voltage have the correct phase relations, there is no output. When the oscillator frequency changes, a direct voltage is produced and applied to the reactance tube.

Connected across the horizontal sweep oscillator tuned circuit, the reactance tube functions as an inductance which varies over a narrow range with a change in bias voltage. Thus, by changing the direct voltage on the reactance tube grid, the horizontal sweep oscillator frequency can be altered. When the circuit is connected properly, this action brings the oscillator frequency back to the proper phase relation with the sync pulses, and thus automatically reduces the discriminator output to zero.

The Sync Discriminator

A schematic diagram of the circuit represented by the discriminator block of Figure 2 is shown in Figure 3A. The sync clipper output is applied across resistor R_3 which is indicated as the "sync input." The sine wave output of the horizontal sweep oscillator is applied across resistors R_1 and R_2 in series, indicated as the "sine wave input". Indicated as e_o, the output of the discriminator is developed across resistors R_4 and R_5 in series and applied to the reactance tube circuit.

The sync input pulses, negative at point (2), cause a flow of electrons. There are two electron paths. One is through R_4, V_1, and R_1. The other is through R_6, V_2, and R_2. V_1 is the same type of tube as V_2, R_4 equals R_5, and R_1 equals R_2, so that the electron flow in both paths is equal.

Under these conditions the voltage across R_4 equals the voltage across R_5, but the polarities are opposite. For R_4, point (1) is positive with respect to point (2), while for R_5, point (3) is positive with respect to point (2). Measured between points (1)—(3), these equal voltages oppose each other so that e_o is zero.

In cases of this kind, the total voltage is the algebraic sum of the separate voltages. If the separate voltages are series opposing, the algebraic sum is equal to the arithmetical difference, and as explained for Figure 3A, the algebraic sum of the voltages across R_4 and R_5 is zero. This action occurs for all input voltages which cause point (2) to be negative with respect to the other end of R_3.

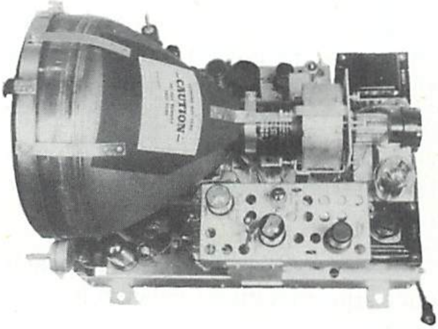
Neglecting for a moment the voltage across R_3, the sine wave output of the oscillator is applied across resistors R_1 and R_2. During one alternation the V_1 plate is positive with respect to the V_2 plate. During the following alternation, the V_2 plate is positive with respect to the V_1 plate. This complete reversal of polarity occurs for each alternation of the input voltage.

During the alternations that the V_1 plate is positive, electrons flow from the junction of R_1 and R_2, through R_3 to point (2), through R_4 to point (1) and through V_1 from cathode to plate, back to R_1. At this time, the V_2 plate is negative with respect to its cathode, therefore V_2 is nonconductive.

With resistance in the circuit, the current will vary directly with the applied voltage, therefore, the voltage across R_4 has the same wave-form as one alternation of the input voltage. With no current in R_5, and therefore no voltage across it, the output voltage e_o is the same as that across R_4.

During the alternations that the V_2 plate is positive, electrons flow from the junction of R_1 and R_2 through R_3 to point (2), through R_5 to point (3), and through V_2 from cathode to plate, back to R_2. At this time the V_1 plate is negative with respect to its cathode and, therefore, is nonconductive. As explained for R_4, during these alternations the voltage across R_5 has the same wave-form as the input voltage but there is no voltage across R_4.

Reviewing the action for a complete cycle, while V_1 is conductive, points (2) and (3) are the same voltage and negative with respect to point (1). While V_2 is conducting, points (1) and (2) are the same voltage and negative with respect to point (3). Thus the wave-form of the output voltage e_o is a replica of the alternating voltage input applied across resistors R_1 and R_2.



The top view of a television receiver chassis. A small chassis mounted near the lower edge of the main chassis contains the "sync amp," the "sync osc," and the "sync disc."
Courtesy Farnsworth Television & Radio Corp.

Earlier in this explanation, it was stated that the discriminator output was direct voltage. To obtain this result, capacitors are connected across resistors R_4 and R_5 as shown in Figure 3B. Due to the rectifying action of the diodes, the polarity of the voltage across each resistor does not change. Therefore, after a few cycles of the sine wave input, the conduction of the diodes charges C_1 and C_2 to the polarity indicated.

To charge C_1, electrons flow from the lower input terminal through R_2 and R_3 to the negative plate of capacitor C_1. Leaving the positive plate, the electrons flow through V_1 to the upper input terminal. In a like manner, when V_2 conducts, the electron flow is from the upper terminal through R_1 and R_3 to the negative plate of capacitor C_2, then from the positive plate through V_2 to the lower terminal.

The total resistance in each charging circuit is relatively low, therefore C_1 and C_2 charge quickly to approximately the sine wave peak. The C_1 discharge path is through R_4, while R_5 forms the discharge path for C_2. R_4 and R_5 have relatively high resistances, therefore, once charged, each capacitor discharges only slightly during the intervals when its diode is not conducting.

Thus, the output e_o is equal to the algebraic sum of the two practically constant voltages E_{C_1} and E_{C_2}, and consequently, it is a direct rather than an alternating voltage as in the case of Figure 3A. However, with only the sine wave input applied, each diode conducts equally, E_{C_1} is equal to E_{C_2}, and these two opposing voltages add to make e_o, Figure 3B, equal to zero. Likewise, with only the sync pulses applied, C_1 charges to the same voltage as C_2, and their sum e_o is zero.

During actual operation, the sine wave and sync pulse inputs are applied simultaneously, and there is zero output only when these inputs are of equal frequencies and proper phase. No matter how carefully it is constructed and tuned, variations of supply voltage or changes of component values due to the differences of temperature cause the frequency of the horizontal sweep oscillator to vary slightly. The purpose of the discriminator is to compare the oscillator output with the sync pulses and convert any variations of frequency or phase into a d-c output voltage of corresponding polarity and amplitude.

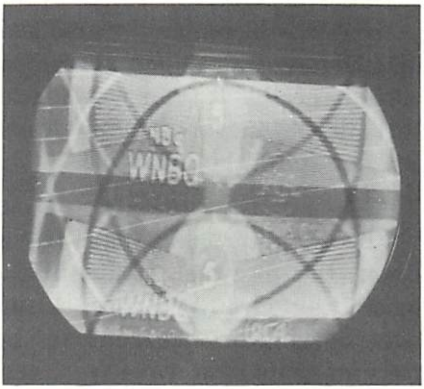
To explain this action, the curves of Figure 4 have been drawn to indicate the combined input voltages applied to point (2) and the plate of each diode in Figure 3. The solid line portions of each curve indicate the alternations during which the diode is conductive, while the broken line portions indicate the nonconductive alternations.

In Figure 4A, the oscillator output has drifted in frequency so that the sync pulse is applied at the positive peak of the conductive alternation of diode V_1. Referring to Figure 3B, this added voltage charges capacitor C_1 to a higher voltage than is possible with the sine wave alone. For the following alternation of the input cycle, diode V_1 is nonconductive while diode V_2 conducts causing C_2 to be charged by the sine wave only. With C_1 charged to a higher voltage than C_2, the output voltage e_o is equal to the difference of potential and point (1) is positive with respect to point (3).

Assume now that the oscillator frequency has drifted so that the sync pulse is applied at the peak of the conductive alternation of diode V_2 as shown in Figure 4B. During the first alternation of this input cycle, capacitor C_1 of Figure 3 charges to the normal sine wave voltage but during the second alternation, the added voltage of the sync pulse charges C_2 to a higher voltage. The output voltage e_o is equal to the difference of potential and point (1) is negative with respect to point (3).

When the oscillator frequency is correct in frequency and phase, as shown in Figure 4C, the sync pulse occurs when the sine wave voltage is passing through zero. Under these conditions, equal voltages are applied to the diodes during the conductive alternations, capacitors C_1 and C_2 are charged equally, and the output voltage remains zero.

Thus, as the oscillator frequency drifts from the correct phase of Figure 4C, toward the extremes of Figures 4A and 4B, there is a corresponding change in the amplitude and polarity of the output voltage e_o. Applied to a reactance tube, this output voltage controls the frequency of the horizontal oscillator and thus maintains the proper synchronism between the sync pulses and the oscillator output.



These multiple images overlapping each other indicate that the vertical sync is inoperative in this TV receiver.

Figure 5A is the diagram of a practical sine wave sweep frequency control system in which V_1 and V_2 are the sync discriminator tubes, V_3 a reactance tube and V_4 an electron coupled oscillator. This circuit is commonly known as the "synchrolock" circuit. As described in an earlier lesson, the V_4 cathode, control grid, and screen grid function as a Hartley oscillator. The plate current pulses develop a square wave voltage across R_{11}. Differentiated by C_{10} and R_{12}, this voltage is applied to the control grid of the discharge tube.

The oscillator frequency may be varied over a narrow range by adjusting R_{13} to change the grid leak bias voltage developed across series connected R_9 and R_{13}. Therefore R_{13} is operated manually as the horizontal hold control.

Although the oscillator output at the V_4 plate has square waveform, the flywheel action in the grid tank circuit causes a sine wave oscillatory current in L_2. Receiving its sine wave from center tapped winding L_1 which is inductively coupled to oscillator coil L_2, and its sync pulses through capacitor C_7 into the L_1 center tap, the sync discriminator of Figure 5A operates in about the same manner as the basic circuit of Figure 3A.

Reactance tube V_3 requires a grid bias of approximately −3 volts for proper operation. However, to provide the desired cathode-plate voltage phase relationships, R_5 is only about 10 ohms. Thus, V_3 plate current in R_5 develops a very small voltage. To obtain the needed bias, the lower end of R_2 and the V_2 cathode are connected to a −3 volt source as indicated. This arrangement places a bias on the V_3 grid because the grid connects through R_4, R_1, and R_2 to the −3 volt source.

Connected from the grid to ground, C_3 charges through R_2, R_1, and R_4 until its upper plate is 3 volts negative with respect to ground, and maintains this charge so long as the discriminator output is zero. When the sine wave input shifts in phase with respect to the sync pulses, the discriminator output adds to or subtracts from the −3 volts and C_3 charges or discharges to the new value.

Although the sync discriminator readily responds to any noise pulses reaching it, the rapid output variations are not passed by filter C_2R_4 and, therefore, these noise "spikes" have little effect on the C_3 charge. Applied to the control grid, the voltage across C_3 provides a variable bias for controlling V_3.

The Reactance Tube Circuit

Functioning as a variable inductance connected in parallel with L_2, reactance tube V_3 varies the oscillator frequency when the V_3 bias is changed. In Figure 5A, the V_3 plate receives an alternating voltage from oscillator coil L_2 through capacitor C_4, while the normal direct voltage is applied through R_8. Also connected across L_2, C_5 and R_5 form a phase shifting circuit that supplies an alternating voltage to the V_3 cathode. C_5 is chosen so its capacitive reactance is much greater than the resistance of R_5, causing a current through R_5 that leads the applied voltage by nearly 90°.

In phase with this current, the voltage E_{R_5} also leads the L_2 voltage by nearly 90° as shown by the curves of Figure 5B. The V_3 plate current indicated as I_{V_3} is 180° out of phase with the cathode voltage, E_{R_5}, and lags the applied voltage, E_{L_2} by 90°.

In a purely inductive circuit, the current lags the voltage by 90°. Therefore, insofar as the oscillator inductor L_2 is concerned, the reactance tube plate current has the same effect as a parallel connected inductor. A decrease of plate current corresponds to an increase of inductance, while an increase of plate current corresponds to a decrease of inductance.

To illustrate the operation of the complete circuit, assume that, with the connections shown in Figure 5A, an increase in oscillator frequency causes V_2 to conduct more than V_1. Under these conditions, voltage E_{R_2} is greater than E_{R_1} and the negative voltage across C_3 and applied to the V_3 grid is increased. The resulting decrease in the reactance tube plate current is equivalent to increasing the inductance represented by the tube. Thus, the total inductance in the oscillator tuned circuit is increased. By this action, the oscillator frequency decreases until the phase relations in the sync discriminator return to the normal condition as shown in Figure 4C, and no further correction voltage is applied to the reactance tube grid circuit.

On the other hand, should the oscillator frequency decrease below the correct value, the sine wave-sync pulse phase relations are such that V_1 conducts more than V_2, the voltage E_{R_1} is greater than E_{R_2} and the sync discriminator produces a positive direct voltage output. The resulting decrease in the net negative bias on the V_3 grid increases its plate current. This is equivalent to a decrease in the inductance represented by V_3, thus causing the oscillator frequency to increase. Again, when the correct frequency is reached, the discriminator output reduces to zero.

In practice, the response of the sine wave type control circuit is immediate and quite effective and, although numerous variations are employed, their basic principles of operation remain the same.

SAWTOOTH WAVE AFC SYSTEM

Figure 6 shows the circuit of a sawtooth type afc system in which the sync pulse phase is compared with that of a sawtooth voltage obtained from the horizontal output amplifier. The phase detector produces a direct voltage which is applied to the multivibrator to control the frequency. This arrangement is also known as the "phase detector" afc system.

Multivibrator Frequency Control

In all multivibrators, the oscillation frequency is determined primarily by the resistance and capacitance of the circuit, but small frequency changes may be obtained by varying the bias on one of the tubes. As the multivibrator frequency changes, the phase relations of the phase detector input waves change and the detector output varies the grid bias of the multivibrator to return it to the proper frequency. However, the direction of frequency change depends upon the polarity of the control voltage and the multivibrator grid circuit to which it is applied.

Perfect synchronism must be maintained by the receiver afc system to provide a picture without tearing or breakup.

Courtesy Westinghouse Electric Corp.

In Figure 6, the control voltage is applied to the grid of tube V_3. The cutoff period of V_4 is determined by the time required for C_6 to discharge through R_7 and R_8 due to a decrease in V_3 plate voltage.

When the control voltage is positive, the V_3 plate current is large, and the V_3 plate voltage falls to a low value. C_6 discharges for a longer time, causing V_4 to be cut off longer. Conversely, when the control voltage is negative, the V_3 plate current is smaller, and the plate voltage decrease is less, C_6 discharges for a shorter time, thus permitting V_4 to conduct sooner. Thus, a positive control voltage decreases the multivibrator frequency, while a negative control voltage increases the frequency.

On the other hand, if the control voltage is applied to the grid of the discharge tube V_4, as it is in some cases, the opposite results are obtained. In this event, a positive control voltage opposes the bias across R_7 and R_8 to make V_4 conduct sooner and increase the oscillator frequency. A negative control voltage aids the bias, holding V_4 in cutoff longer, to decrease the frequency of oscillation.

The Double Diode Phase Detector

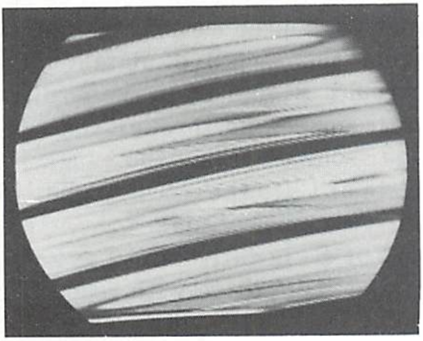
As shown in Figure 6, positive sync pulses are applied through C_1 to the V_2 plate, and negative pulses through C_2 to the V_1 cathode. Thus, the diodes conduct in series, charging C_1 and C_2 to the polarities shown.

During this charging interval, electrons flow from the C_2 positive plate, through V_1 and V_2 to the C_1 negative plate. From the C_1 positive plate, electrons flow through the voltage source to the negative plate of C_2, thereby charging the capacitors to the peak of the applied pulses. The charge voltages E_{C_1} and E_{C_2} bias the V_2 plate negative and the V_1 cathode positive.

To understand how these biases are applied to the diodes, notice that, in series with each other, V_2 and V_1 are connected in parallel with R_1 and R_2. Resistor R_1 is equal to R_2, and V_2 offers the same resistance to current as V_1. During sync pulses, when the diodes are conducting equally, the voltage across V_2 is equal to that across V_1. Therefore, the junction between the V_2 cathode and V_1 plate has the same potential (zero with respect to ground) as point X, the junction between R_1 and R_2 which connects through R_4 to ground.

In the intervals between sync pulses, the capacitor voltages E_{C_1} and E_{C_2} produce electron flow from the negative plate of C_1, through R_1 and R_2 to the positive plate of C_2, and through the voltage source from the negative plate of C_2 to the positive plate of C_1. This current makes the upper end of R_1 negative and the lower end of R_2 positive with respect to point X. Thus, with respect to point X and ground, the V_2 plate is negative by the voltage E_{R_1} while the V_1 cathode is positive by the voltage E_{R_2}.

From a winding on the horizontal output transformer, positive voltage pulses are integrated by R_3 and C_3 to form a sawtooth wave. The action is illustrated by the wave-forms E_P and E_{C_3} at the lower left in the Figure. The connecting dashed lines indicate that C_3 charges rapidly by the positive going pulses from the output transformer, and discharges slowly between pulses. This sawtooth voltage is applied to the cathode of V_2 and the plate of V_1, causing the respective voltages to vary slightly above and below that of point X. However, the sawtooth amplitude is not great enough to overcome the bias voltages E_{R_1} and E_{R_2} and cause conduction of the diodes. Also, C_1 and C_2 discharge only slightly due to the electron flow through R_1 and R_2 between sync pulses. Therefore, only the sync pulse peaks have amplitude great enough to overcome the biases and cause conduction of the diodes. This momentary conduction, through the low resistance of V_1 and V_2, recharges C_1 and C_2.



The picture becomes a meaningless blur when the TV receiver lacks horizontal sync.

As a result of this sync pulse conduction, the application of the sawtooth voltage to the V_2 cathode determines whether V_1 conducts more, the same, or less than V_2. Briefly then, point X assumes a voltage determined by the polarity and magnitude of the sawtooth voltage during the interval of diode conduction.

In detail, the phase detector circuit operates in the following manner: As the sawtooth voltage swings positive and negative about its zero axis, it makes the V_1 plate and V_2 cathode alternately positive and negative with respect to ground. When the sync pulse arrives: (1) if the sawtooth is passing through zero, the diodes conduct equally; (2) if the sawtooth is positive, the positive V_1 plate makes this diode conduct more than V_2, since V_2 has the positive sawtooth applied to its cathode; (3) if the sawtooth is negative, the negative V_2 cathode makes this diode conduct more than V_1, since V_1 has the negative sawtooth applied to its plate.

When V_1 conducts more than V_2, the excess electrons from the V_1 plate flow to the upper plate of C_3. This action charges C_2 to a higher voltage than that across C_1. On the other hand, when V_2 conducts more than V_1, the excess electrons needed flow from the upper plate of C_3, through V_2 to charge C_1 to a higher voltage than that across C_2.

In the intervals between sync pulses, C_1 and C_2 discharge through R_1 and R_2 as explained. However, the discharge current is greater for the capacitor with the higher charge, and the additional electron flow is carried by R_4. If the charge on C_1 is higher than that on C_2, the excess electrons flow from C_1 through R_1 to point X, and down through R_4 to ground. R_2 carries only the C_2 discharge current. If C_2 has the highest charge, the excess electrons flow from ground up through R_4 to point X, and through R_2 to C_2. Due to the difference in the direction of the electron flow in R_4, the voltage E_{R_4} makes point X negative when C_1 has the higher charge, and positive when C_2 has the higher charge.

In Figure 7, the sync pulse and sawtooth voltage waveforms are aligned to show their phase relations. Figure 7A shows the phase existing when the sweep oscillator frequency is correct. Here, the steeply rising edges of the sawtooth pass through zero at the instant the sync pulses arrive. The diodes conduct equally to place equal charges on C_1 and C_2. With equal discharge currents between sync pulses, there is no excess electron flow in R_4. With no voltage across this resistor, point X is at ground potential. Thus, there is no voltage applied from point X through the double time constant network, R_5C_4, to the grid of V_3 when the sweep oscillator frequency is correct.

An increase in multivibrator frequency results in the phase relationship of Figure 7B. When the sync pulses arrive, the sawtooth has already passed through zero, and is rising in the positive direction. Applied to the plate of V_1, the positive sawtooth voltage causes heavier conduction in this diode to charge C_2 more than C_1 is charged by V_2. With the larger charge on C_2, electron flow up through R_4 makes point X positive in the intervals between sync pulses. This positive control voltage is coupled through R_5 to the grid of V_3 to decrease the multivibrator frequency. The control voltage is generated by the phase detector and applied to V_3 until the sweep oscillator frequency reduces to the correct value to provide the phase conditions of Figure 7A.

Attractive table model receiver with side controls.
Courtesy Emerson Radio and Phonograph Corp.

If the multivibrator frequency is lower than normal, the phase relations of Figure 7C are produced. In this case, the sawtooth voltage is decreasing from its negative peak, and has not yet reached zero when the sync pulses arrive. Applied to the V_2 cathode, the negative sawtooth voltage has the same effect as applying a positive voltage to the plate of this diode. Therefore, V_2 conducts more than V_1 and charges C_1 to the higher voltage. Between sync pulses, the excess electron flow from C_1 passes down through R_4 making point X negative with respect to ground. Applied to the grid of V_3, this negative control voltage increases the oscillator frequency. As before, when the sweep frequency has been brought to the proper value, the phase relations of Figure 7A reduce the phase detector output to zero.

The Triode Phase Detector

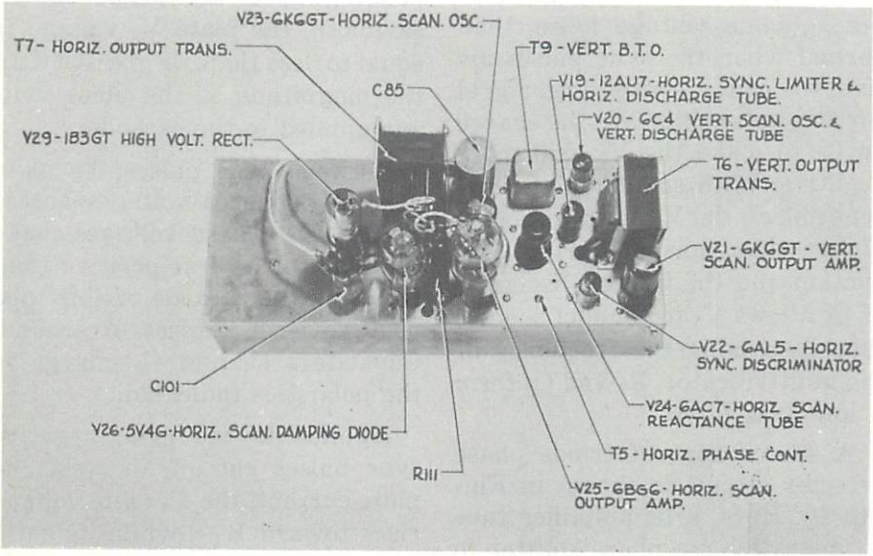
Also a sawtooth type afc system, the circuit of Figure 8 employs triode tube V_1 as the phase detector. Applied to the V_1 plate, the sawtooth is produced by R_7 and C_2 from the horizontal sweep output. C_3 is a blocking capacitor and negative going sync pulses are applied through C_1 to the cathode. The sync pulse amplitude is much greater than the sawtooth. A low positive voltage is applied to the plate of V_1 through resistors R_1, R_2 and R_3. In operation, the sawtooth wave varies the plate voltage above and below its average value, causing corresponding variations of plate current.

Each sync pulse drives the V_1 cathode highly negative. This action is the same as driving both the plate and grid highly positive. As a result, there is produced a pulse of plate current and also a pulse of grid current during the sync pulse interval. The pulses of grid current charge C_4 to the polarity indicated. Between sync pulses, this charge on C_4 biases the grid negative with respect to ground. Thus, grid current occurs only when the sync pulse is applied to the cathode of V_1.

The triode phase detector action is based upon the manner in which grid current varies with changes in plate voltage. With the grid at a given positive voltage with respect to the cathode, and a positive direct voltage on the plate, the grid current has some constant value. If the plate is made more positive, more electrons flow to the plate, and grid current decreases. If plate current is reduced by making the plate less positive, grid current increases.

In the circuit of Figure 8, the voltage across C_4 is part of the total bias in the grid-cathode circuit of multivibrator tube V_6. The magnitude of E_{C_4} depends upon the amplitude of the V_1 grid current produced by the applied sync pulses. For any given sync pulse, the amplitude of the grid current pulse depends upon the plate voltage at the instant the sync pulse arrives. The total plate voltage is the sum of the sync pulse voltage applied to the cathode and the direct voltage applied to the plate through the resistors from B+, plus or minus the instantaneous sawtooth wave voltage.

Figure 9 shows the phase relationships of the applied sawtooth and pulse voltage. If the multivibrator frequency is correct, the sawtooth crosses the zero axis when the sync pulses arrive as shown in Figure 9A. Hence, the sawtooth voltage neither adds to nor subtracts from the plate voltage at these instants. The pulses of grid current maintain the charge on C_4 and therefore the bias on the V_6 grid such that the multivibrator continues to oscillate at the desired frequency.


V23-6K6GT-HORIZ. SCAN. OSC.
T7-HORIZ. OUTPUT TRANS.
T9-VERT. B.T.O.
C85
V19-12AU7-HORIZ. SYNC. LIMITER & HORIZ. DISCHARGE TUBE.
V20-6C4 VERT. SCAN. OSC. & VERT. DISCHARGE TUBE
V29-1B3GT HIGH VOLT. RECT.
T6-VERT. OUTPUT TRANS.
V21-6K6GT-VERT. SCAN. OUTPUT AMP.
V22-6AL5-HORIZ. SYNC. DISCRIMINATOR
C101
V24-6AC7-HORIZ. SCAN. REACTANCE TUBE
V26-5V4G-HORIZ. SCAN. DAMPING DIODE
T5-HORIZ. PHASE CONT.
R111
V25-6BG6-HORIZ. SCAN. OUTPUT AMP.

A top chassis view of vertical and horizontal deflection circuits. The circuits necessary for oscillator frequency control are also included in this unit.

Courtesy Scott Radio Lab.

If the multivibrator frequency increases for some reason, the sawtooth waves pass through zero sooner than they should, and thus are rising in the positive direction when the sync pulses arrive, as shown in Figure 9B. This positive instantaneous sawtooth voltage is added to the plate voltage so that the sync pulses at the cathode produce smaller pulses of grid currents. Because of the smaller grid current pulses, the average charge on C_4 decreases, allowing the V_6 grid to become less negative. Larger pulses of V_6 plate current cause the plate of this tube to decrease to a lower than normal positive voltage during conduction. The resulting heavier discharge of C_8 holds V_5 in cutoff for a longer time, thus decreasing the multivibrator frequency.

When the multivibrator frequency decreases below the correct frequency, the phase condition of Figure 9C results. With the V_1 plate voltage lower than normal when the sync pulses arrive, the consequently larger grid current pulses increase the charge on C_4 to make the V_6 grid more negative. With smaller plate current pulses, the V_6 plate voltage is higher than normal during conduction and the lighter discharge of C_8 allows V_5 to conduct sooner, thus increasing the frequency of the multivibrator. R_6 and C_5 form a low pass filter.

A second type of triode phase detector circuit is shown in Figure 10. Here, sync amplifier tube V_1 operates as a phase splitter to apply positive going sync pulses through C_1 to the grid of V_2 and negative going sync pulses through C_2 to the cathode of phase detector V_2. From the horizontal amplifier output, a sawtooth voltage is applied to the plate of V_2. Again, plate and grid current are produced during sync pulses only, and the grid current pulse amplitude varies inversely as the plate voltage.

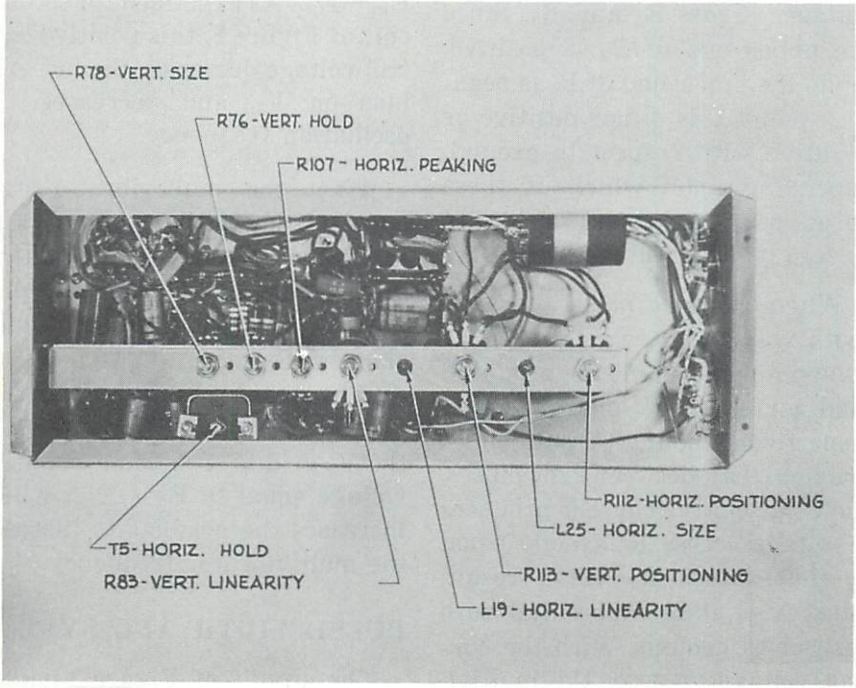
Also, during the sync pulse intervals, the total or net V_2 plate voltage is equal to the algebraic sum of the pulse voltage on the cathode and the instantaneous sawtooth voltage on the plate. When a pulse makes the cathode negative, it is the same as though both grid and plate were made positive. To this difference of potential, an additional positive pulse is applied to the grid. Depending upon the phase of the sawtooth, the plate V_2 voltage is equal to, less than, or greater than the magnitude of the pulse voltage applied to the cathode.

Between sync pulses, V_1 plate current produces voltages across R_1 and R_2. These voltages make the plate of V_1 less positive than B+, and the cathode of this tube positive with respect to ground. Capacitors C_1 and C_2 charge to the polarities indicated.

Applied to the grid, negative sync pulses cut off V_1. With no plate current, the V_1 plate voltage rises toward B+, while its cathode voltage falls toward ground potential. Coupled through C_1 and C_2, these voltage changes apply a positive pulse to the grid of V_2 and a negative pulse to its cathode, as indicated. This action produces grid current in the form of electron flow from ground up through R_2 into C_2, from C_2 to the cathode of V_2, to the grid and into C_1, and from C_1 through R_1 to B+. This electron flow increases the charge on C_1, and slightly discharges capacitor C_2.

At the end of the sync pulse interval, V_1 conducts, and the voltages produced across R_1 and R_2 restore the V_1 plate to its former lower value and the cathode to its original positive value. With these voltage changes C_1 begins to discharge, and C_2 to charge. However, V_2 is now non-conductive. Therefore, capacitor C_1 current consists of electron flow from the negative plate of C_1, through R_4 and R_5 to the negative plate of C_2, and from the positive plate of C_2 through V_1 into the positive plate of C_1. This current makes point X negative with respect to the lower end of R_5.

However, at the same time, capacitor C_2 recharges also by means of electron flow from ground up through R_3 and into C_2, and from C_2 through V_1 and R_1 to B+. This action produces a voltage across R_3 which makes the upper end of this resistor positive with respect to ground. At any instant, the magnitude of this charging current is determined by the voltage at the cathode of V_1. The V_1 cathode voltage is independent of the V_2 grid current, therefore, the



The under chassis view of the unit shown in the preceding illustration.

Courtesy Scott Radio Lab.

current in and voltage across R_3 between sync pulses are the same for each cycle, regardless of the phase relations between the pulses and sawtooth waves. However, the voltages across R_4 and R_5 depend upon the amount of charge added to C_1 during the sync pulse intervals. This charge is determined by the V_2 grid current, which varies inversely with the plate voltage, as mentioned.

The control voltage at point X is applied through R_6 to the grid of multivibrator tube V_3. With respect to ground, this voltage is equal to the algebraic sum of the voltages across R_5 and R_3. Since the upper end of R_3 is positive, while the upper end of R_5 is negative, point X is either positive or negative with respect to ground, depending upon which of these voltages is the larger; or it may be zero if these voltages are equal.

When the sync pulse and sawtooth voltage phase relation is as shown in Figure 9A, the produced grid current in V_2 charges C_1 by some given amount. Circuit values are such that, between sync pulses, the C_1 discharge current produces a voltage across R_5 exactly equal to that across R_3. As a result, point X is at zero potential with respect to ground. With the control voltage at zero, the multivibrator oscillates at the proper frequency, determined by the setting of R_9, and thus maintains the phase relation of Figure 9A.

If some circuit change occurs to increase the frequency of the multivibrator, its output has leading phase as shown in Figure 9B. The V_2 plate is more positive than normal when the sync pulses arrive, and the produced grid current pulses have lower amplitude, thus charging C_1 less. Between sync pulses, the C_1 discharge current is smaller, providing a smaller voltage across R_5. However, the voltage across R_3 is unchanged, therefore, point X supplies the V_3 grid a positive voltage equal to $E_{R_3}-E_{R_5}$. As explained for the circuit of Figure 8, this positive control voltage decreases the net grid bias on V_3, and decreases the oscillation frequency.

When the multivibrator frequency is lower than normal, Figure 9C, the lower V_2 plate voltage during sync pulse intervals permits larger grid current which charges C_1 more. The larger C_1 discharge current makes E_{R_5} greater than E_{R_3}. Consequently, the V_3 grid is supplied a negative voltage equal to $E_{R_5}-E_{R_3}$, which increases the net bias to increase the multivibrator frequency.

PULSE-WIDTH AFC SYSTEM

The circuit of Figure 11 illustrates an afc system of the pulse-width type. Called the "synchroguide" circuit, it employs the control tube V_1 in place of the phase comparers of the previous systems. The V_2 circuit is the horizontal sweep oscillator, which incorporates an LC-stabilized blocking oscillator type. Coil L_3 and capacitor C_8 form the stabilizing tank circuit. The sawtooth voltage output is formed across C_9 which charges through R_{12} and discharges through V_2, L_1, and L_3. Grid leak bias is developed by capacitor C_7 and resistor R_{10}. Instead of returning to ground, the lower end of R_{10} connects to the junction between R_3 and R_4. These latter resistors are in the cathode circuit of V_1, and therefore a voltage exists across them due to V_1 plate current.

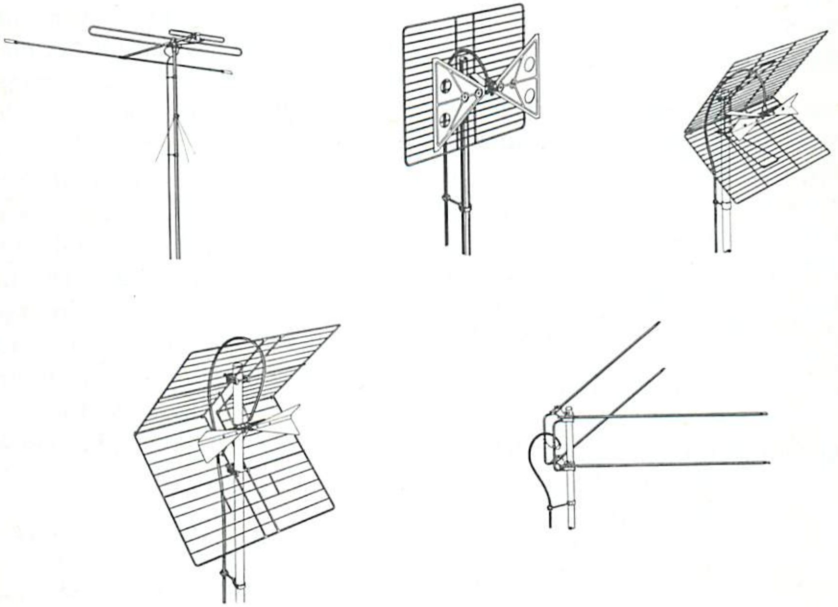
Applied through C_1, positive going horizontal synchronizing pulses cause V_1 to conduct. The plate current pulses charge C_4 to the polarity indicated. This charge biases the cathode positive, holding V_1 in cutoff except during the sync pulse intervals. Between sync pulses, C_4 discharges slightly through R_3 and R_4, thus making the upper end of each positive with respect to ground. That is, R_3 and R_4 form a voltage divider to which the voltage E_{C_4} is applied. In series with the negative bias across R_{10}, positive voltage E_{R_4} decreases the net bias on the grid of V_2 by a small amount.

The frequency of a blocking oscillator varies inversely as the bias applied to its grid. Regardless of its initial value, the bias decreases toward the conduction point at a rate determined by the RC time constant in the grid circuit. Therefore, the higher the initial value, the longer this period of bias decrease before the tube begins to conduct, and the lower the frequency of oscillation.

In the circuit of Figure 11, the initial bias on the grid of V_2 is determined by the negative voltage across R_{10} and the positive voltage across R_4. Since E_{R_4} is in series opposition to $E_{R_{10}}$, at any instant, the net bias is equal to $E_{R_{10}} - E_{R_4}$. Thus, a change in E_{R_4} changes the V_2 grid bias, and therefore the oscillation frequency. At a given time, the magnitude of E_{R_4} depends upon the charge on C_4. This charge depends upon the length of time that V_1 conducts during the sync pulse intervals. In turn, the V_1 conduction time depends upon the accuracy of the blocking oscillator frequency with respect to the frequency or repetition rate of the incoming sync pulses. Thus, generated by the control tube circuit, E_{R_4} serves as a control voltage which maintains the accuracy of the horizontal blocking oscillator frequency.

In detail, the action of the control tube is as follows: Positive sync pulses are coupled from the sync amplifier through C_1 to the grid of V_1. These pulses are shown in the upper row of waveforms in Figure 12. Taken from across C_9, Figure 11, the sweep oscillator sawtooth output is coupled through R_9 and C_2 to the V_1 grid. These components and R_1, R_2 and C_3 integrate the sawtooth wave to produce the voltage waveform shown in the second row in Figure 12. By itself, the integrated sawtooth wave does not have sufficient amplitude to drive V_1 into conduction. However, a sync pulse adds to the sawtooth, thus swinging the grid far enough in the positive direction to produce plate current in V_1. The addition of the pulse and sawtooth input voltages is shown in the lower row of wave-forms in Figure 12.

In the V_1 cathode circuit, capacitor C_4 charges when V_1 conducts plate current, and discharges while V_1 is cut off, as mentioned. The longer the tube conducts, during any given sync pulse interval, the greater the charge on C_4. The greater the charge on C_4, the larger the voltage E_{C_4}, and also the larger the voltage across R_4 in the intervals between sync pulses.



A variety of antenna assemblies designed by Amphenol for both vhf and uhf television reception.

Courtesy American Phenolic Corp.

Referring to the lower row of curves in Figure 12, the horizontal dashed line indicates the V_1 grid voltage level above which the grid allows plate current, and below which it holds V_1 cut off. In each case, for Figures 12A, B, and C, plate current is permitted for some fraction of the sync pulse interval. The length of time V_1 conducts during each sync pulse is determined by the pulse-sawtooth phase relation. That is, this phase relation determines the duration or "width" of the pulse of V_1 plate current, hence the name, pulse-width afc system.

When the oscillator frequency is correct, the phase relation is as shown in Figure 12A. The sawtooth wave reaches its positive peak approximately midway through the sync pulse interval. From its peak, the integrated sawtooth falls rapidly. The resulting grid voltage wave-form is shown by the lower curve. As indicated here, V_1 plate current exists during approximately one-half of the sync pulse interval. This current charges C_4, Figure 11, just enough so that E_{R_4} together with $E_{R_{10}}$ result in the V_2 grid bias which provides the correct blocking oscillator frequency.

If the blocking oscillator frequency increases, the sawtooth wave reaches its positive peak sooner, as shown in figure 12B. Here, the fall of the sawtooth occurs shortly after the rising front of the sync pulse. Therefore, V_1 conducts only briefly, E_{R_4} is small, and the larger than normal initial net bias on V_1 decreases the oscillator frequency. Conversely, as shown in Figure 12C, the sawtooth reaches its peak later when the oscillator frequency is too low. V_1 conducts for almost all of the sync pulse interval to produce a large value of E_{R_4}. The smaller than normal initial bias on the grid of V_1 permits the oscillator frequency to increase.

Connected across C_4 in the circuit of Figure 11, resistor R_5 and capacitor C_5 comprise an "anti-hunt" network. During the voltage change across C_4, this network causes a delay which is necessary to prevent over control. That is, without this network, the control voltage causes the oscillator frequency to "hunt", or vary above and below the correct frequency before finally stabilizing. The delay action results from the fact that, whenever C_4 begins to charge or discharge, the voltage change is applied to the R_5C_5 circuit also in which C_5 is much larger than C_4.

During sync pulse intervals, when V_1 is conducting, C_5 charges through R_5, thus absorbing most of the electron flow. That is, R_5 and C_5 act as a partial short circuit so that electrons do not enter C_4 at a considerable rate until after C_5 has charged for a time. Likewise, between sync pulse intervals, C_5 discharges through R_4, R_3, and R_5. This discharge current produces a voltage across R_3 and R_4 which opposes the discharge of C_4, and therefore maintains the voltage across C_4 until C_5 has discharged for a time. Due to this delay action, a long series of pulses are required to cause an appreciable change of voltage across C_4.

GRUEN AFC SYSTEM

Less commonly employed than the three systems described so far is the Gruen circuit, shown in Figure 13. Here, the horizontal oscillator V_3 operates as a Hartley sine wave oscillator, the frequency of which is controlled by variable resistance tube V_2. As in all systems, a portion of the sweep output is fed back to the phase detector where it is compared with the sync pulses. The output of the phase detector is a direct voltage fed to the afc tube to control the bias. A change in the afc tube bias, caused by a change in the frequency, returns the oscillator to the correct frequency.

Referring to tube V_1 of Figure 13, diodes D_1 and D_2 are connected in a balanced discriminator circuit. Resistors R_1 and R_3 of equal value are connected across D_2 and D_1 respectively. The cathodes of D_1 and D_2 are connected together while the D_2 plate is connected to ground.

When negative sync pulses are applied to the cathode, both diodes conduct charging capacitor C_1 to the indicated polarity.

One electron path can be traced from the D_1 cathode to its plate, to the lower plate of C_{13}, from C_{13} upper plate to ground, through the sync pulse source to the C_1 negative plate, and from the lower C_1 plate to the D_1 cathode. Thus the conduction of D_1 charges C_{13} to the polarity shown. For D_2, electrons flow from cathode to plate, to ground, through the sync source to the C_1 negative plate, and from the lower C_1 plate to the D_2 cathode.

During the interval between sync pulses, C_1 discharges. One electron path is from ground, through R_1 to C_1 and another from ground to C_{13}, and from this capacitor through R_3 to C_1. This action develops the indicated R_1 and R_3 voltages which are equal and opposite with respect to ground. Also, this electron flow discharges C_{13}. With equal and opposite voltages developed across resistors R_1 and R_3, the output is determined by the charge on capacitor C_{13}. In order to develop a correction voltage, negative pulses are fed back from the horizontal amplifier output through a low pass network consisting of R_9, R_8, and C_{13}. This network integrates the pulses to provide a sawtooth voltage. The sawtooth voltage then is applied to the phase detector and compared with the sync pulses.

The phase of the sync pulses and sawtooth for three operating conditions are shown in Figures 14A, 14B, and 14C. In Figure 14A, the applied signals are in phase and the detector output is the C_{13} charge voltage. A condition where the oscillator is too fast is shown in Figure 14B. At the moment that the sync pulse occurs, the sawtooth voltage is going negative, placing a negative voltage on the plate of D_1 and a positive voltage on the D_2 plate. This results in less conduction of D_1 and more conduction of D_2. The smaller D_1 current pulses charge C_{13} to a lower voltage.

Between sync pulses, the C_{13} discharge current produces a smaller voltage across R_3 than is produced across R_1 by the discharge of C_1. Therefore, at the junction of R_2 and R_3, the algebraic sum of E_{R_1} and E_{R_3} is a positive voltage. This positive control voltage is applied through low pass filter R_2 and C_3 to the grid of V_2. R_4 and C_4 form an anti-hunt network to stabilize the voltage across C_3.

In the circuit of Figure 13, triode V_2 serves as a variable resistance in series with C_6 and R_7 across the oscillator tank circuit. The plate of V_2 connects to B+ through R_6 which limits the current through the tube. Resistor R_5, bypassed by C_5, carries the combined plate current of the horizontal oscillator and V_2. The voltage across R_5 sets the operating point for V_2.

With a positive voltage applied to the grid of V_2, the plate current increases and the plate to cathode resistance is decreased. In series with C_6 across the tank inductance the reduced resistance allows C_6 to have greater shunt-

The need for television servicemen increases as more and more homes acquire one or more "extra" television receivers such as this used in the game room.

Courtesy Raytheon Mfg. Co.—
TV and Radio Operations

ing effect on the tank inductance, thus resulting in a lower frequency.

In Figure 14C, the phase of the sync pulse and sawtooth voltages are shown when the oscillator is low in frequency. The sawtooth voltage is positive at the D_1 plate and negative at the D_2 plate. This results in greater conduction of D_1 and a decrease in conduction of D_2. The net d-c output is more negative due to the larger voltage on C_{13}. Consequently, a negative control voltage is applied to the grid of V_2.

With a decrease in V_2 plate current, due to a negative voltage at the grid, the plate resistance is high. This higher resistance reduces the shunting effect of C_6 on the tank circuit, thus resulting in an increase of frequency.

AFC CIRCUIT TROUBLES

Any tearing of lines, break up of the picture, or production of multiple or greatly distorted images indicates loss of horizontal synchronism. The most obvious locations of defects causing this trouble are the afc circuits, the horizontal deflection circuits, and the sync circuits. However, it should be remembered that the sync signals are brought to the receiver by the picture carrier, and therefore must pass without attenuation or distortion through all or most of the picture signal circuits before they arrive at the input of the sync section. Therefore, when the trouble is not found in either the afc, sync, or deflection circuits, it is possible that an earlier stage is responsible for loss or distortion of the horizontal sync pulses.

Of course, the various horizontal deflection frequency controls can become misadjusted to cause loss of sync, in which case the proper control adjustment restores synchronism. Usually, when the trouble is due to a circuit defect, it is impossible to obtain synchronism by adjusting the controls. In some cases, the picture can be made to "hold" briefly, but jumps out of sync again a short while after the adjustment has been made. This situation indicates trouble in the afc circuits.

As a typical trouble that could develop in an afc circuit, consider the phase detector of Figure 6. Capacitor C_1 connects to the phase splitter plate which is at a positive voltage. Should this capacitor become leaky, electrons would flow from ground up through R_4 and R_1 and through C_1 to the phase splitter plate. This current would make the upper end of R_4 positive with respect to ground. Applied to the grid of V_3, this positive voltage could make the multivibrator oscillator frequency shift out of the range of the control of R_8 and L_1.

Another cause of incorrect voltage across R_4 is a change in resistance of R_1 or R_2. For example, should R_2 increase in resistance, the phase detector circuit becomes unbalanced so that the voltage at point X is far from the value normally applied to the V_3 grid.

In the circuit of Figure 10, capacitor C_8 at the lower right forms the sawtooth voltage indicated as applied to the plate of V_2. If C_8 becomes leaky, this sawtooth voltage decreases in amplitude, or becomes zero, depending upon the extent of the leakage. With low sawtooth voltage on the phase detector plate, the grid current pulses all have about the same amplitude, regardless of frequency error in the horizontal multivibrator. As a result, the correction voltage, if any, produced at point X, is not great enough to cause the needed change in bias on the grid of V_3. With insufficient control voltage produced by the afc circuit, the oscillator continues to operate off frequency.

These possible example faults are just a few that could exist in an afc circuit. However, they serve to indicate the importance of understanding the basic principles of operation when it becomes necessary to analyze the reason for some failure in the horizontal deflection system.

The home type television receivers are the most numerous by far, although there are many applications of television other than just home entertainment. In some of these other applications, it is necessary that the picture be considerably larger than on a home receiver, so that it can be viewed by a large group of people. The next lesson describes methods by which the television image is projected onto a screen to provide the desired large pictures for such situations.

* * *

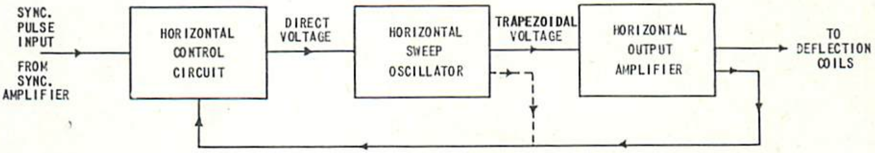


FIGURE 1

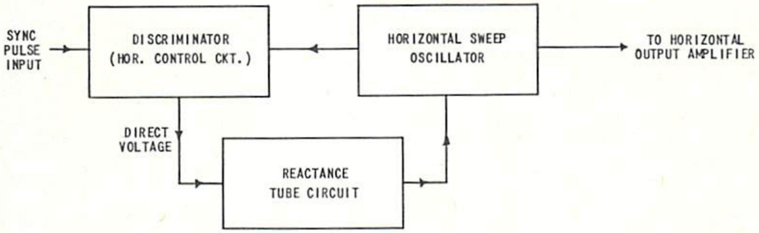

SYNC PULSE INPUT
DISCRIMINATOR (HOR. CONTROL CKT.)
HORIZONTAL SWEEP OSCILLATOR
TO HORIZONTAL OUTPUT AMPLIFIER
DIRECT VOLTAGE
REACTANCE TUBE CIRCUIT

FIGURE 2

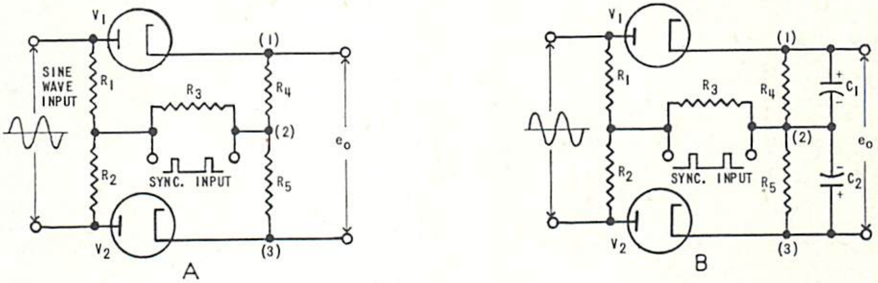


FIGURE 3

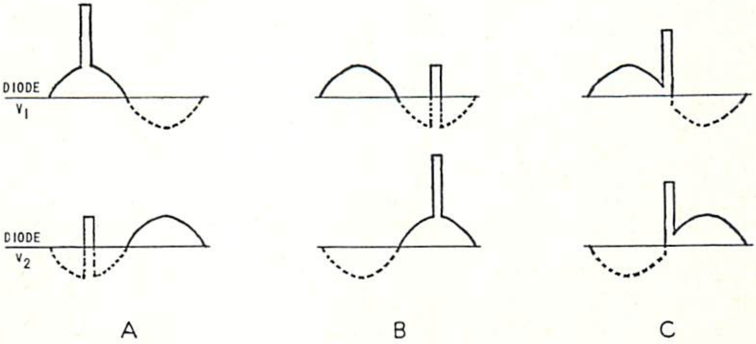


FIGURE 4

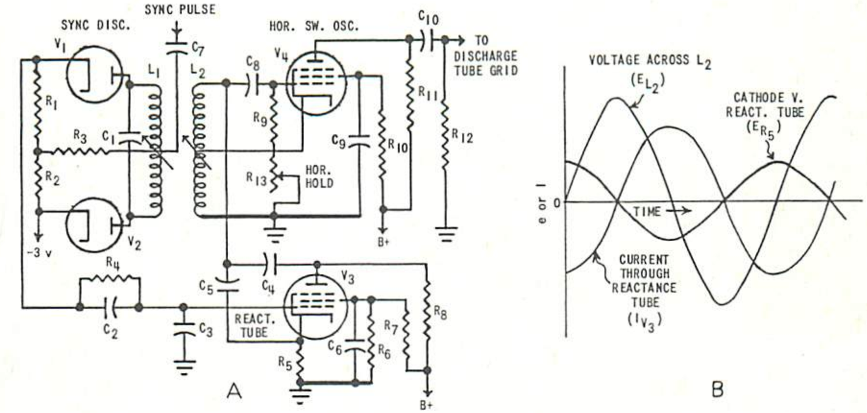


FIGURE 5

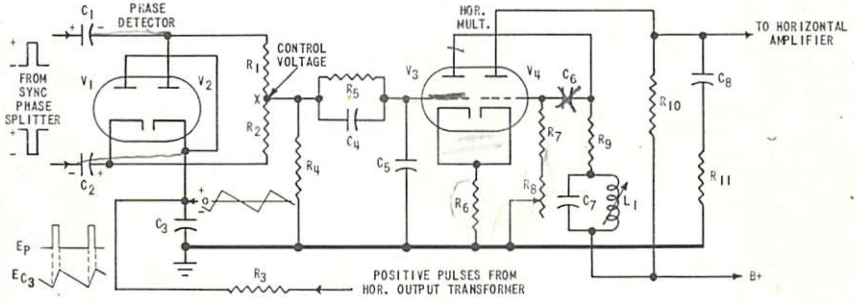


FIGURE 6

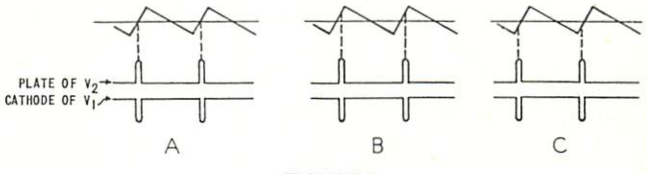


FIGURE 7

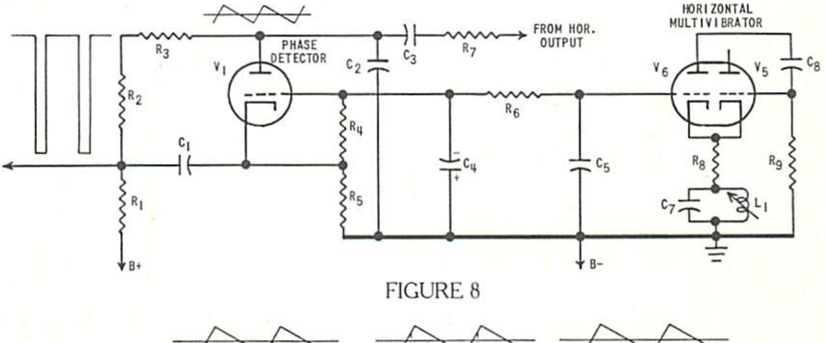


FIGURE 8

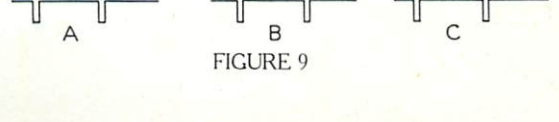


FIGURE 9

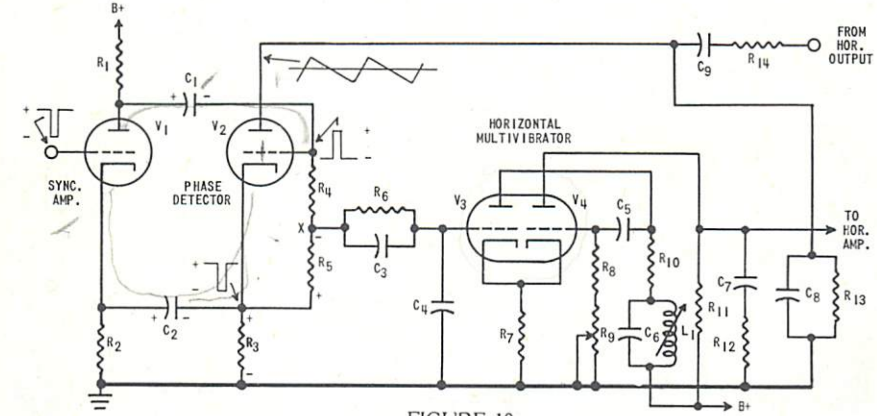


FIGURE 10

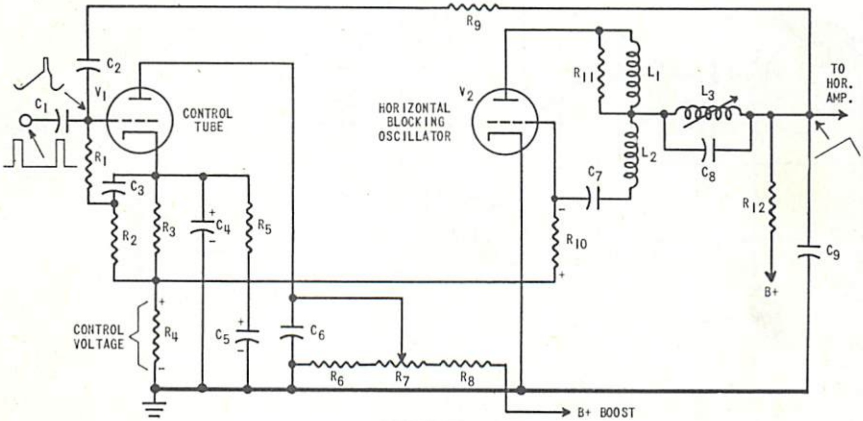


FIGURE 11

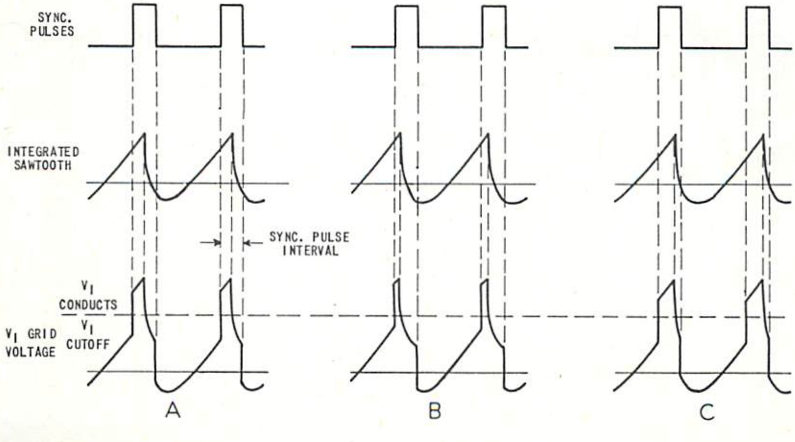


FIGURE 12

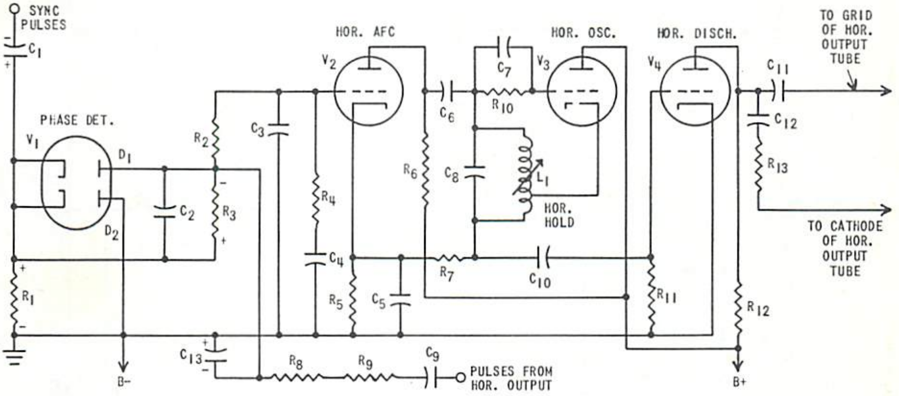


FIGURE 13

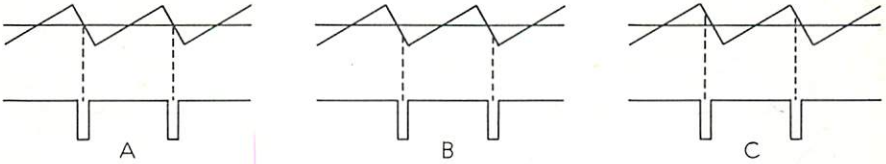


FIGURE 14

FROM OUR *Director's* NOTEBOOK

TODAY

YESTERDAY is gone forever. Tomorrow never comes. Today is in my own hands.

If I shirk Today's task, I shall be adding to my wasted Yesterdays.

If I postpone Today's duty, I shall be increasing Tomorrow's burden.

If I accomplish what Today sets before me, I shall be doing my best to atone for Yesterday's failures, and prepare for Tomorrow's successes.

Therefore, I will endeavor so to use my time and opportunities that Today shall leave me a little wiser and abler than it found me.

Yours for success,

W. C. De Vry

DIRECTOR

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